The Savvy Aviator #59: EGT, CHT and Leaning

July 3, 2008

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Columnist

The Savvy Aviator

Of the many tasks that we have to perform as pilots, leaning the engine is one of the simplest. Leaning is vastly easier than shooting a circling approach in low IMC, picking the smoothest route through a cold front or deciding when to overhaul the engine. Yet no subject I know seems to trigger more discussion and debate among pilots, nor to provide more misinformation and bad advice.

Although I usually devote this column to maintenance-related topics, aircraft owners seem to ask me more questions about leaning procedures than just about any other subject. It's obvious to me that, despite the simplicity of this subject, it remains poorly understood by a lot of aviators. So I thought it might be worthwhile to revisit my approach to leaning, and then address some of the questions that pilots seem to have about it.

The best source I know for in-depth information about optimal powerplant management is the 2-1/2-day **Advanced Pilot Seminars** (APS) course developed by my good friends George Braly, Walter Atkinson and John Deakin. This outstanding seminar is offered both as a "live" course several times a year in Ada, Okla., and occasionally elsewhere, and is also available in a home-study, on-line version. Tuition is about $1000 for the live course and about $400 for the on-line course. I've taken both the live and on-line versions, and both are excellent.

The objective of the APS course is to offer pilots an in-depth understanding of powerplant management, both theory and practice. It offers a huge amount of information on the subject, and most APS graduates liken the experience to drinking from a firehose. But many pilots are reluctant to invest the time, money and neurons into gaining that level understanding of powerplant management. Many are just looking for a simple, cookbook-like approach to leaning that doesn't require a rocket scientist to master.

About the Author ...

Mike Busch has been a pilot for more than 40 years and 7,000 hours, and an aircraft owner and CFI for more than 35 years. He became increasingly interested in the maintenance aspects of aircraft ownership about 20 years ago, and ultimately earned his A&P/IA.

Mike is also a prolific aviation writer, with hundreds of technical articles published in Air Facts, ABS Magazine, Aviation Safety, AVweb, CPA Magazine, Cirrus Pilot Magazine, IFR, Light Plane Maintenance, and The Aviation Consumer. He co-founded AVweb in 1995 and served as its editor-in-chief for more than seven years.

Mike conducts weekend **"Savvy Owner Seminars"** at which aircraft owners learn how to obtain better aircraft maintenance while spending a lot less money.

Mike was recently honored by the FAA as National Aviation Maintenance Technician of the Year for 2008.

Forget the POH!

Mixture Control

Most Pilot Operating Handbooks (POHs) provides precisely such simple, cookbook-style guidance. Most call for operating the engine in cruise at "recommended lean mixture," which is typically defined as leaning to peak EGT and then richening until EGT drops by 50°F. (Or in shorthand, "50°F ROP.") Many POHs also authorize operating at "best economy mixture" (defined as peak EGT) for power settings less than 55-to 65-percent power.

Unfortunately, this POH guidance leaves a lot to be desired. 50°F ROP is almost precisely the *worst* possible mixture setting from the standpoint of engine longevity. The maximum cylinder head temperature (CHT) and peak internal cylinder pressure (ICP) occurs almost precisely at 50°F ROP. So using the "recommended lean mixture" assures that your engine operates at the hottest, most stressful corner of its operating envelope.

"Best economy mixture" (peak EGT) is only slightly better, providing a bit cooler CHTs and a bit less internal stress on the engine, but not by much. Furthermore, peak EGT is certainly *not* the best economy mixture; minimum brake specific-fuel consumption (BSFC) occurs at a substantially leaner mixture than that, well lean of peak EGT (LOP).

Why would so many aircraft manufacturers publish such bad advice in their POHs? Well for one thing, back in the 1960s and 1970s when many of the POHs were written, the relationships between EGT, CHT and ICP were not as well understood as they are today. The conventional wisdom at that time was that richer mixtures were better for the engine, and leaner mixtures were worse. A culture of fear evolved, promulgated by the flight instructors of the day: If you leaned too aggressively, you'd blow up your engine.

With today's sophisticated instrumentation, we now know that this isn't true. The hottest, most stressful mixture is about 50°F ROP, and mixtures that are richer *or* leaner are better for the engine. At 75-percent cruise power, you want to stay well away from that worst-case mixture setting, either by operating at least 100°F ROP (preferably richer) or at least 20°F LOP (preferably leaner), take your pick.

Given the choice between operating ROP or LOP, LOP operation has some compelling advantages: It's cleaner, cooler, less stressful on the engine, and uses a lot less fuel. Or, as the latest APS mantra goes: "Leaner is greener."

Also, many aircraft engines in the 1960s and 1970s typically would run unacceptably rough if you tried to lean them beyond peak EGT. Today, with tuned fuel-injector nozzles and digital engine monitors, we are able to operate these engines deep in the LOP regime without roughness. Even most carbureted engines can be operated at least somewhat LOP if the pilot knows what he's doing.

That POH "recommended lean mixture" (50° ROP) does offer a reasonable compromise between best power and best economy. What 50°F ROP does *not* provide is good engine longevity, which is something that the manufacturers don't care much about but owners definitely do. (Premature cylinder replacement is a major expense item for an aircraft owner, but a revenue item for the manufacturer.)

CHT is the best proxy we have in the cockpit for peak internal cylinder pressure (ICP). Peak ICP and peak CHT occur at almost exactly the same mixture setting. This is the mixture that's hardest on the engine because it creates the greatest stresses. Except at low power settings -- say 60-percent power or less -- it's a good place to avoid if you care about engine longevity.

So while many pilots still follow the antediluvian POH guidance, we can do a lot better. Note that the leaning recommendations in the POH are *not* limitations; they are mere suggestions (and often not very good ones, in my view). A pilot is under no regulatory obligation to follow them (which, in my view, is a good thing).

How I Lean

Over the past decade, I've evolved a dead-simple approach to leaning that has worked very well for me in my Cessna T310R turbocharged twin. My engines obviously love it, since they're both now more than 900 hours beyond TBO and running great. With minor variations, my approach should work for just about any piston-powered airplane.

CHT Gauge

Perhaps the most controversial aspect of my technique is that I don't use EGT as a leaning reference for cruise flight. EGT is extremely useful for troubleshooting engine problems, but as a leaning reference it leaves quite a bit to be desired in my opinion. That's because optimum EGT varies with cruise power setting, altitude and temperature, so leaning by reference to EGT turns out to be relatively complicated.

I find it a lot easier to lean in cruise by reference to CHT and fuel flow. In this respect, I depart from what is taught in the APS course. APS teaches an EGT-based approach that's more accurate but more complicated. I use a CHT-based approach that's dead simple yet still puts me in the ballpark and obviously has made my engines live long and prosper.

Here's how I do it. First, I decide upon my objective: Do I want to go fast (i.e., achieve maximum airspeed) or do I want to go far (i.e., achieve minimum fuel consumption)?

If my objective is to go fast, then I lean so that the CHT of my hottest-running cylinder does not exceed a pre-established target value. That target depends on the aircraft and to some extent the OAT, but for most legacy aircraft (Beech, Cessna, Mooney, Piper, etc.) and most OATs, a target of about 380°F works well. (For more recently-designed aircraft like the Cirrus SR22 or Diamond DA42, with their superior engine-cooling systems, 350°F is a better number.) At unusually cold OATs, the target figure should be lowered a bit.

If the CHT of the hottest-running cylinder exceeds the target value, then I enrichen a bit more (if ROP) or lean a bit more (if LOP) to bring the CHT down to the target. Conversely, if the hottest CHT is lower than the target value, I can save a bit of fuel by leaning a bit more (if ROP) or gain a bit of speed by enrichening a bit more (if LOP).

Personally, I always cruise LOP for all the reasons cited earlier (cooler, cleaner, cheaper, greener), but your mileage may vary.

If my objective is to go far, then I lean so that my GPS-coupled fuel totalizer system shows forecast fuel remaining at my destination to be not less than my target minimum fuel reserve (which for me is one hour of fuel at cruise fuel-flow). If the totalizer forecasts that I will arrive at my destination with less fuel than this, then I lean further until the totalizer does show enough reserve fuel. If I find that I cannot lean enough to achieve the necessary fuel-reserve figure without experiencing engine roughness, then I know I'll need to make a fuel stop.

If you choose to cruise ROP, then you also have to make sure that you don't lean so far as to exceed your target CHT. If you can't find a mixture that simultaneously yields the required fuel reserve and doesn't exceed the target CHT, then you'll either have to reduce power, switch to LOP operation, or make a fuel stop.

If you don't have a GPS-coupled fuel totalizer, then you can calculate your reserves manually from fuel quantity, fuel flow and GPS-derived time-to-destination, but that's a lot more work. For anyone who flies a lot of long-distance fuel-critical missions (like I do), a GPS-coupled fuel totalizer is probably number 3 on the "Things You Just Gotta Have" list, right behind a digital engine-monitor and real-time, satellite weather in the cockpit.

Frequently-Asked Questions

When I operate LOP, my EGTs are noticeably higher than when I operate ROP. Won't those higher EGTs harm my engine?

Indeed, if you run 20° LOP instead of 100° ROP, your EGTs will be higher -- 80°F higher, to be exact. This is nothing to worry about. At cruise power, your engine is not capable of producing EGTs high enough to harm anything. When I cruise my T310R LOP (which is the only way I fly it these days), I generally see EGTs in the mid-1500°F range. Given the extraordinary longevity and reliability I've obtained from my engines, they're clearly quite content with those EGTs.

Alcor EGT Gauge

If I operate at peak EGT or LOP, don't I risk burning my exhaust valves?

This question belies a common misconception that burned exhaust valves are caused by high EGTs. This is not correct. Burned exhaust valves are caused by valve-guide wear and valve-stem wear, and the best way to keep that from happening is (1) to keep CHTs down, and (2) to run a lean mixture to minimize build-up of combustion byproducts on the valve stem. The leaner you operate (while keeping CHTs at prudent levels), the happier your exhaust valves will be.

Why do you recommend keeping CHTs at or below 380°F, while TCM sets its CHT red line at 460°F and Lycoming sets it at 500°F? Aren't you being excessively conservative?

Both TCM and Lycoming specify CHT limits (460°F and 500°F, respectively) that should be considered emergency limits, not operational limits. Allowing your CHT to get anywhere close to those values for significant periods of time will most likely result in premature exhaust-valve problems and increased incidence of cylinder-head fatigue cracking. I do not like to see CHT above about 400°F, which is the temperature at which the aluminum alloy from which your cylinder head is made loses one-half its tensile strength. (The strength decreases rapidly as the temperature rises above 400°F.) For legacy aircraft, I recommend a maximum target CHT of about 380°F just to provide a little extra cushion, and consider any CHT above 400°F to be grounds for "doing something right now" to get it down. (For modern designs like the Cirrus and Diamond, reduce those CHTs by 30°F or so.)

The higher the power setting, the further away from 50°F ROP you need to stay to keep CHT at or below the target. As power decreases, this "zone to avoid" around 50°F ROP becomes narrower and narrower. When power gets down to about 60 percent, the avoidance zone disappears and you can run the mixture pretty much anywhere you please without overtemping or overstressing anything. (The APS folks refer to this zone to avoid as "the red box.")

In my view, the best way to manage our piston engines is the same way we manage turbine engines: by limiting temperature, specifically by CHT (which is the best proxy we have for ICP). For best engine longevity, set the mixture somewhere that produces CHTs no higher than 380°F (or 350°F for modern designs). This can be very ROP, or slightly LOP, or even right at peak if the power is low enough. What's important is that you limit CHTs to a maximum target value. How you accomplish that is less important from the standpoint of longevity.

My engine monitor uses a spark-plug gasket probe on cylinder number two because the threaded boss on that cylinder is already occupied by the factory CHT probe. Is that why my number two CHT always seems to run hot?

Yes it is. A spark plug gasket probe generally results in a CHT reading that's about 40°F hotter than a normal, threaded probe on the same cylinder. To avoid this problem, you can purchase a "piggyback" probe for your engine monitor that will screw into the threaded boss on the cylinder, and that will allow the factory probe to be piggy-backed on top of it. The piggy back probe sometimes reads slightly lower than the regular probe, but it's a whole lot closer than the spark-plug gasket probe.

JPI Engine Monitor

All this LOP stuff may be fine for you fuel-injected guys, but I fly a Cessna 182 with a carbureted O-470 engine. I've been told that LOP operation is a bad idea for carbureted engines. Do you agree?

LOP operation is fine for any engine that can run smoothly in that configuration. However, LOP operation requires fairly even mixture distribution among the cylinders. That's sometimes difficult to achieve in a carbureted engine, particularly the O-470 engine in a Cessna 182 (which is famous for its poor mixture distribution).

There are a couple of techniques you can use to improve the mixture distribution of your carbureted engine and thereby enable the engine to be leaned more aggressively before it starts to run rough. One is to use a touch of carb heat during cruise (particularly in low OATs). The other is to avoid full-throttle operation, backing off the throttle until you can just see the slightest drop in MP. The warm induction air and the slightly cocked throttle plate both improve fuel atomization and mixture distribution in your engine, and will enable you to lean more aggressively before the engine starts running rough.

You should feel quite comfortable experimenting with these techniques to see if you are able to operate LOP without creating uncomfortable engine roughness. Contrary to popular belief, you can't hurt anything by operating LOP. If you get your engine to run smoothly LOP, I suggest you try it (and you'll probably like it). If you can't, then you'll have to be content with ROP operation.

My Cessna 182 has a Texas Skyways O-520 conversion. I also have an Electronics International UBG-16 engine monitor and FP-5 fuel flow system. Texas Skyways is dead-set against LOP operations. They recommend operation

ROP up to a maximum of 1825°F of CHT plus EGT combined. For my engine, this normally equates to 50°F ROP. How would you recommend I operate this engine?

The notion of using CHT+EGT as a leaning target has absolutely no scientific basis behind it. Electronics International does recommend this technique it in its UBG-16 users manual, but it's poor advice in my opinion. CHT is the most important parameter for cylinder longevity, because it correlates with ICP. I disregard EGT altogether when leaning, although EGT is enormously useful for troubleshooting. If you use EGT+CHT as a leaning reference (as Electronics International suggests), the EGT overwhelms the CHT in the sum and you lose the most important part of the information (which is CHT).

Don't get me wrong: The Electronics International UBG-16 is an excellent engine monitor, and E.I.'s technical support is top-notch. But the UBG-16 user's manual ... not so much, in my opinion.

I suggest you keep CHTs at or below 380°F (or 350°F for modern designs). There is no limit for EGT. My cylinders generally see EGTs in the high 1500s and they obviously haven't caused a longevity problem. My cylinders and valves use exactly the same metallurgy as yours.

You caution against excessive CHTs, but is it possible for CHTs to be too cold?

Yes, it's possible to run CHTs so cold that the tetraethyl lead (TEL) in the 100LL is not properly scavenged and starts creating metallic lead deposits in the combustion chamber and lead-fouling the spark plugs. However, in most engines, it takes *very* cool CHTs (down in the mid-200s °F or lower) for an extended period of time (hours) for this to cause a problem. We usually see this problem in airplanes used for fish spotting, pipeline patrol, search and rescue, and other "loiter-mode" operations. Unless you fly at very low power settings (e.g., 50 percent) and/or at very high altitudes and very cold OATs (e.g., FL240 and -30°C), it's not usually a problem.

Xerion AuRACLE

I fly a Cessna 172 with no CHT or EGT or fuel flow instrumentation. How should I lean my engine?

After stabilizing in cruise and reducing power to the desired cruise RPM, slowly lean the mixture until you feel the onset of perceptible engine roughness. Then slowly richen just to the point that the roughness goes away. With your limited instrumentation, that's the best you can do ... and it's not a bad technique.

Having said that, I would strongly recommend that you consider installing a digital engine monitor in your airplane. To my way of thinking, having an engine monitor is even more important in a four-cylinder, single-engine airplane than it is in six-cylinder single or a twin. If you fly a four-cylinder single and you lose a cylinder in flight, you don't have much left.

See you next month.